

Mesons and baryons in the holographic soft-wall model

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Mesons and baryons are considered in soft-wall holographic approach based on the correspondence of string theory in AdS space and conformal field theory in physical space-time. The model generates Regge trajectories linear in n and $J(L)$ for the hadronic mass spectrum. Results obtained for heavy-light meson masses and decay constants are consistent with predictions of HQET. In the baryon sector applications to the nucleon electromagnetic form factors and generalized parton distributions are discussed.

Based on the gauge/gravity duality [1] a class of AdS/QCD approaches was recently successfully developed for describing the phenomenology of hadronic properties. In order to break conformal invariance and incorporate confinement in the infrared region two alternative AdS/QCD backgrounds have been suggested in the literature: the “hard-wall” approach [2], based on the introduction of an IR brane cutoff in the fifth dimension, and the “soft-wall” approach [3–12], based on using a soft cutoff. In series of papers [9–12] we developed the soft-wall approaches, which have been successfully applied for the study of meson and baryon properties. Here we present a summary of recent results: meson mass spectrum and decay constants of light and heavy mesons, nucleon electromagnetic form factors and generalized parton distributions. Our starting point are the effective $(d + 1)$ dimensional actions formulated in AdS space in terms of boson or fermion bulk fields, which serve as holographic images of mesons and baryons. For illustration we consider the simplest actions — for scalar fields ($J = 0$) [10]

$$S_0 = \frac{1}{2} \int d^d x dz \sqrt{g} e^{-\varphi(z)} \left[g^{MN} \partial_M S(x, z) \partial_N S(x, z) - \left(\mu_S^2 + \Delta V_0(z) \right) S^2(x, z) \right].$$

and $J = 1/2$ fermions [7, 11]:

$$\begin{aligned} S_{1/2} = & \int d^d x dz \sqrt{g} e^{-\varphi(z)} \left[\frac{i}{2} \bar{\Psi}(x, z) \epsilon_a^M \Gamma^a \mathcal{D}_M \Psi(x, z) - \frac{i}{2} (\mathcal{D}_M \Psi(x, z))^\dagger \Gamma^0 \epsilon_a^M \Gamma^a \Psi(x, z) \right. \\ & \left. - \bar{\Psi}(x, z) \left(\mu_\Psi + \varphi(z)/R \right) \Psi(x, z) \right], \end{aligned}$$

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where S and Ψ are the scalar and fermion bulk fields, \mathcal{D}_M is the covariant derivative acting on the fermion field, $\Gamma^a = (\gamma^\mu, -i\gamma^5)$ are the Dirac matrices, $\varphi(z) = \kappa^2 z^2$ is the dilaton field, R is the AdS radius, $\Delta V_0(z)$ is the dilaton potential. μ_S and μ_Ψ are the masses of scalar and fermion bulk fields defined as $\mu_S^2 R^2 = \Delta_M(\Delta_M - d)$ and $\mu_\Psi R = \Delta_B - d/2$. Here $\Delta_M = \tau_M = 2 + L$ and $\Delta_B = \tau_B + 1/2 = 7/2 + L$ are the dimensions of scalar and fermion fields, which due to the QCD/gravity correspondence are related to the scaling dimensions (twists τ_M, τ_B) of the corresponding interpolating operators, where $L = \max |L_z|$ [4]. These actions give information about the propagation of bulk fields inside AdS space (bulk-to-bulk propagators), from inside to the boundary of the AdS space (bulk-to-boundary propagators) and bound state solutions - profiles of the Kaluza-Klein (KK) modes in extra-dimension, which correspond to the hadronic wave functions in impact space. We suppose a free propagation of the bulk field along the d Poincaré coordinates with four-momentum p , and a constrained propagation along the $(d + 1)$ -th coordinate z (due to confinement imposed by the dilaton field). In particular, it was shown [4] that the extra-dimensional coordinate z corresponds to the light-front impact variable. It was also shown [8] that in case of the scattering problem the sign of the dilaton profile is important to fulfill certain model-independent constraints. But we recently showed [12], that in case of the bound state problem the sign of the dilaton profile is irrelevant, if the action is properly set up. Moreover, in solving the bound-state problem, it is more convenient to move the dilaton field from the exponential prefactor to the effective potential [4, 12]. Then we use a KK expansion for the bulk fields factorizing the dependence on d Poincaré coordinates x and the holographic variable z . E.g. in case of scalar field it is given by $S(x, z) = \sum_n S_n(x) \Phi_n(z)$, where n is the radial quantum number, $S_n(x)$ is the tower of the KK modes dual to scalar mesons and Φ_n are their extra-dimensional profiles (wave-functions) satisfying the Schrödinger-type equation with the potential depending on dilaton field. Then using the obtained wave functions Φ_n we calculate matrix elements describing hadronic processes. Finally, we present the results of our calculations for mesonic decay constants (Table 1) and spectrum (Tables 2 and 3), nucleon helicity-independent generalized parton distributions (GPDs) in Fig.1. Note, by construction we reproduce the power scaling of nucleon electromagnetic (EM) form factors at large Q^2 and our predictions for the EM radii are compare well with data:

$$\begin{aligned}
 \langle r_E^2 \rangle^p &= 0.91 \text{ fm}^2 \text{ (our)}, 0.77 \text{ fm}^2 \text{ (data)}; \langle r_E^2 \rangle^n = -0.12 \text{ fm}^2 \text{ (our)}, -0.12 \text{ fm}^2 \text{ (data)}, \\
 \langle r_M^2 \rangle^p &= 0.85 \text{ fm}^2 \text{ (our)}, 0.73 \text{ fm}^2 \text{ (data)}; \langle r_M^2 \rangle^n = 0.88 \text{ fm}^2 \text{ (our)}, 0.76 \text{ fm}^2 \text{ (data)}.
 \end{aligned}$$

 Table 1. Decay constants f_P (MeV) of pseudoscalar mesons.

Meson	Data	Our
π^-	$130.4 \pm 0.03 \pm 0.2$	131
K^-	$156.1 \pm 0.2 \pm 0.8$	155
D^+	206.7 ± 8.9	167
D_s^+	257.5 ± 6.1	170
B^-	193 ± 11	139
B_s^0	$253 \pm 8 \pm 7$	144

Table 2. Masses of light mesons

Meson	n	L	S	Mass [MeV]			
π	0	0,1,2,3	0	140	1355	1777	2099
π	0,1,2,3	0	0	140	1355	1777	2099
K	0	0,1,2,3	0	496	1505	1901	2207
$f_0[\bar{n}n]$	0,1,2,3	1	1	1114	1600	1952	2244
$f_0[\bar{s}s]$	0,1,2,3	1	1	1304	1762	2093	2372
$a_0(980)$	0,1,2,3	1	1	1114	1600	1952	2372
$\rho(770)$	0,1,2,3	0	1	804	1565	1942	2240
$\phi(1020)$	0,1,2,3	0	1	1019	1818	2170	2447
$a_1(1260)$	0,1,2,3	1	1	1358	1779	2101	2375

Table 3. Masses of heavy-light mesons

Meson	J^P	n	L	S	Mass [MeV]			
$D(1870)$	0^-	0	0,1,2,3	0	1857	2435	2696	2905
$D^*(2010)$	1^-	0	0,1,2,3	1	2015	2547	2797	3000
$D_s(1969)$	0^-	0	0,1,2,3	0	1963	2621	2883	3085
$D_s^*(2107)$	1^-	0	0,1,2,3	1	2113	2725	2977	3173
$B(5279)$	0^-	0	0,1,2,3	0	5279	5791	5964	6089
$B^*(5325)$	1^-	0	0,1,2,3	1	5336	5843	6015	6139
$B_s(5366)$	0^-	0	0,1,2,3	0	5360	5941	6124	6250
$B_s^*(5413)$	1^-	0	0,1,2,3	1	5416	5992	6173	6298

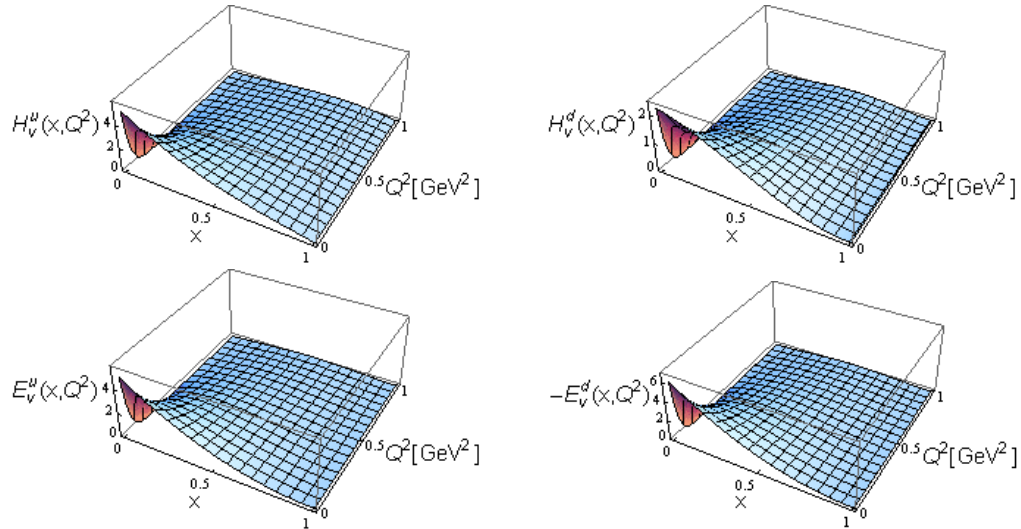


Figure 1: Nucleon helicity-independent GPDs in momentum space

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